Exercises for Radiative Transfer in Astrophysics (SS2013)

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Exercise sheet 10

Spherical circumstellar dusty envelope model (part V: non-LTE CO lines)

4. **Adding non-LTE effects** We continue with the 1-D envelope model with lines.

   (a) Lower the density such that $\rho_{\rm dust,0} = 10^{-21}$ gram/cm^3.

   (b) Add a file `numberdens_h2.inp` for the H_2 number density (this has the same format as the file for CO).

   (c) Change the last number in the `lines.inp` to 1, and add a line with "h2" to tell RADMC-3D that CO is now thermally coupled to H_2 (H_2 molecules are the collision partner of CO).

   (d) Add a line in `radmc3d.inp` making `lines_mode` to the value 3 (LVG + EscProb).

   (e) Introduce (if you have not yet already done so) a radial velocity field according to the following formula:

   $$v(r) = v_{\rm in}\sqrt{\frac{r_{\rm in}}{r}} \tag{8}$$

   with $v_{\rm in} = -1$ km/s.

   (f) Make a file `escprob_lengthscale.inp` with the same format as the usual numberdensity files, but now containing a length scale for each cell. Take this length scale to be everywhere the same, and take it to be, for instance, the outer radius of the cloud.

   (g) Output the level populations of $J = 3$ and $J = 4$ by calling `radmc3d image iline 4 writepop`. Look at the file `levelpop_co.dat`.

   (h) Compare to the LTE values (computed when `lines_mode`=1).

   (i) Play with the length scale and with the velocity field, and describe what happens.

   (j) Try higher and lower values of $\rho_{\rm dust,0}$ (i.e. higher and lower gas density and CO number density, too).